

Guidelines for Developing a Guardrail Manual for Low-Volume Roads

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Designing and maintaining a “forgivable roadside” is an important concept to promote highway safety. However, it is not always possible, feasible or “affordable,” particularly on Low-Volume Rural Roads (LVR). The results of recent research have provided reasonably good guidelines for roadside safety, barrier rail and end treatments on state highways and other major roads. Generally these sophisticated models and guidelines do not apply to LVR. Local governments have tens of thousands of miles of LVR where rights-of-way are narrow, clear zones and traversable slopes cannot be provided and budgets are inadequate for a multitude of competing problems. The Kansas Department of Transportation (KDOT) contracted with the authors to review the state-of-the-art of roadside safety, interview local roads personnel, study local roadside situations and develop guidelines on low-volume roads, roadside safety and barrier rail use. The computer program ROADSIDE was adapted to LVR conditions and simplified guidelines for its use where developed for LVR conditions. Computer results based on a range of Kansas LVR conditions were compiled and presented in a manual for easy use by Kansas personnel with responsibility for LVR safety. The paper presents information on adapting ROADSIDE for use on LVR and a sample of results from the Kansas Manual. Key words: guardrail, roadside safety, clear zone, low-volume road safety.

INTRODUCTION

Kansas State University (KSU) recently completed a research contract with Kansas Department of Transportation (KDOT) to develop guidelines for the use of guardrail on low-volume roads (LVR) in Kansas according to safety and effectiveness. The computer program ROADSIDE is widely used to assist designers in making informed choices regarding alternate, guardrail design concepts. ROADSIDE follows the Barrier Guide cost-effective methodology. The ROADSIDE program was adapted to Kansas LVR parameters. LVR are generally defined as roads with 400 ADT, although many LVR's have much lower ADT's.

A comprehensive review of the research literature was conducted to explore and gather information on the use of guardrail on LVR. The purpose of this information search was to identify the general elements used to determine the need for guardrail on LVR and to review any specific guidelines already in use by other states. The principal findings from this literature review are presented below.

Existing Guidelines on LVR

Currently most states are using or developing guidelines for the installation of guardrail on state highways based on the *Roadside Design Guide*. Published by the American Association of State Highway and Transportation Officials. These AASHTO guidelines recommend guardrail if the consequences of hitting a roadside fixed object or running off the road would be more serious than those associated with striking the guardrail (1). The guidelines to warrant guardrail should consider two roadside conditions: embankment cross sections and fixed objects. The AASHTO guidelines do not have embankment warrants specifically for LVR.

Guardrail Guidelines for Roadside Embankments

According to the *Roadside Design Guide*, a guardrail is warranted relative to roadside embankments based on the fill section height and the reciprocal of the fill section slope, without considering the ADT. Arnold mentions that several states use the *Roadside Design Guide* warrants directly, or in a modified form, regardless of ADT (2). Many states use the computer program ROADSIDE. However, this program has to be adapted for LVR. Some states have done this and developed curves and tables for LVR.

North Carolina considers speed and the length of embankment. For example, for an ADT of 400, 55 mph (88.2 kph), and a 2 1/2:1 slope, guardrail would be warranted on a 30 foot (9.1 Meters) embankment if it were over 150 feet (45.7 meters) long, on a 20 foot (6.1 meters) embankment if it were over 1,000 feet (305 meters) long, and on a 17 foot (5.2 meters) embankment if it were over 2,000 feet (610 meters) long.

The Arnold report presented guidelines to assist in evaluating the need for guardrail on secondary roads (2) (generally ADT's ≤ 10,000).

Missouri developed guidelines for guardrail on LVR in Missouri which considers the total life cycle cost of guardrail installations, physical characteristics of the hazard, severity or costs of accidents, and expected frequency of accident occurrence (3). For design speeds of 40 and 50 mph, (64 and 80 kph) guardrail installation was found to be not economically justified for any of the conditions used (slopes 2:1, 3:1; lateral offset of the hazard of 6, 8, and 10 feet (1.8, 2.4 and 3.0 meters); and length of the hazard of 100, 500, and 1000 feet (30.5, 152 and 305 meters) regardless of the embankment height, when the ADTs were lower than 400 vehicles. For design speed of 60 mph (96 kph) the guardrail was warranted for ADTs between 350 and 400 vehicles only when the embankment height was of 20 feet (6.1 meters) for designs with cross slope of 2:1 or greater and certain combinations of lateral offset and length

of the hazard: 6-100, 6-500, 6-1000, 8-500, and 8-1000 feet-feet (1.8-30.5, 1.8-152, 1.8-305, 2.4-152, and 2.4-305 meters-meters).

Guardrail Guidelines for Roadside Obstacles

Most states have followed the AASHTO guidelines (*Roadside Design Guide*, 1989) for roadside obstacles and clear zone distances. Arnold reported that twenty-seven of thirty-nine states contacted were using the AASHTO guidelines but with a policy that considered exceptions on low-volume, low-speed roads (2). Exceptions to the AASHTO guidelines on LVR generally call for clear zone distances of 7 ft (2.1 m) to 10 ft (3.0 m) for ADT's between 400 and 750. Two states waived clear zone or do not install guardrail with design speed < 40 mph (64 knp) or ADT < 1250.

Pigman and Agent discussed the development of warranting guidelines for clear zones in the state of Kentucky based on Kentucky accident severities (4). The computer program ROADSIDE was used to obtain the warranting guidelines.

Type of Guardrail Systems and their Costs

Once the guardrail is warranted the next problem that the local agencies face is to determine the type of guardrail needed for low volume, low speed roads. The AASHTO *Roadside Design Guide* (1989), describes a number of operational and experimental guardrail systems. Three of the operational systems that are currently being used in virtually all of the LVR applications throughout the USA are (Stephens, 1992): the G-1 cable system, the G-2 weak post W-Beam, and the G-4 strong post W-Beam. The G-1 and G-4 systems have variations in the type of post used.

The Roadside Approach for Performing Guardrail Assessments

Although the Roadside Design Guide presented warrants for the need for guardrail based on embankment and roadside obstacle criteria, the recommendation was made that highway agencies develop specific guidelines for their agency based on a cost-effectiveness selection procedure based on the application of the computer program ROADSIDE (1). The procedure to evaluate alternatives should be based on a cost-effectiveness analysis with or without the ROADSIDE computer program. ROADSIDE allows the user to calculate the present worth and annualized cost (including accidents, installation, repair and maintenance) of a specific safety improvement at a specific location. The real value of the program is that it allows a cost comparison of alternative improvements, including the do-nothing alternative.

The ROADSIDE program was adapted to analyze guardrail on Kansas LVR. Each jurisdiction must input their own jurisdiction-specific data to obtain good local results. This process is emphasized in this paper and is presented below. A sample of Kansas results are presented to illustrate the type of results possible.

The third computer screen in ROADSIDE allows input of the variable data specified to an alternative being evaluated. Following is a discussion of how each of the items, 2 through 15, was decided on for applying ROADSIDE in the embankment and fixed object analyses for Kansas:

- Item 2. Traffic Volume. The traffic volume was varied between 400 vehicles per day (vpd) to 100 vpd with a constant growth factor of 1% per year.
- Item 3. Roadway Type. A two-lane, two-way road was used for the analyses by setting an undivided roadway with one lane adjacent to the hazard in ROADSIDE. The lane width was assumed to be 3 meters.
- Item 4. Adjustment Factors. ROADSIDE allows adjustment to the baseline encroachment to account for roadway curvature and grade. For the analyses, a value of 1.0 was used.
- Item 5. Traffic Volume and Encroachments. ROADSIDE calculates this item by assuming splitting of the previously input traffic volume evenly by direction, applying the encroachment defined earlier, and adjusting the baseline encroachment by the factors in item.
- Item 6. Design Speed and Encroachment Angle. The following speeds were used in the calculations: 50, 60, 70, 80 and 90 km/hr. The program default encroachment angles were used in the analyses.
- Item 7. Hazard Definition. In ROADSIDE, a hazard is defined with a lateral offset (A) from the edge of the nearest driving lane, longitudinal length (L) parallel to the roadway, and width (W) - generally perpendicular to the roadway. Values used in the Kansas study are discussed below.

Lateral Offset

On Kansas unpaved rural roads, there is no way to describe or show a typical section from which to measure the offset. This must be determined in the field. Depending upon local blading practices, the usable roadway width (traveled way) may vary from one local jurisdiction to another and in fact may vary from before and after a section is bladed. The only practical solution is for the person in charge of road and street operation and maintenance to determine the record the outer limits of the normally traveled way.

The following parameters were used in the analyses:

- For embankment analysis
 - In the embankment analysis, 60 m (200 ft) was used for the length of both the guardrail and the embankment. Different lengths were tested with the ROADSIDE program and 60 m yielded the smallest height of fill at which guardrail became cost-effective. Thus, this value is conservative on the side of safety.
 - Length: 60 m (200 ft.) For both (guard and embankment), 6 m (20 ft) on culverts
 - Width of Guardrail: 0.3 m (1 ft)
 - Width of Embankment: variable depending on embankment height and cross slope.
 - Foreslopes: 1:2, 1:3, 1:4
 - Height: 0 to 10 m (0 to 32.8 ft)
 - Lateral Offset for Guardrail: 0.0, 0.3, 1.3, 3m
 - Lateral Offset for Embankment: 3 m (10 ft)
- For the fixed objects analysis
 - For the fixed objects analysis a 60 m (200 ft) section of guardrail was compared with a 0.3m (1ft) by 0.3m (1ft) fixed object.
 - Length. 0.3m (1 ft)
 - Width. 0.3 m (1 ft)
 - Lateral Offset of the Fixed Objects. 0, 0.3, 1, 2, 3, 3m
- Item 8. Initial Collision Frequency. These values are calculated by ROADSIDE based on previously input data.

- Item 9. Severity Index. Severity indexes, (SIs) are estimates of the societal costs associated with an average accident with a given feature. ROADSIDE uses the Sis to determine the cost of accidents. Five values are needed to perform the analyses. One for each: the upstream side, the upstream corner, the force, the downstream corner, and the downstream side of the texture. For both, embankment analysis and fixed objects analysis, the Sis used were taken from the ROADSIDE Users Manual, Appendix A (A Cost-Effectiveness Selection Procedure; a user's guide and documentation for the computer program ROADSIDE.)
- Item 10. Project Life and Discount Rate. For the purpose of this project, an anticipated life of 20 years and a discount rate of 4 percent were used.
- Item 11. Installation Costs. Based on the data provided by KDOT the installation cost was \$82.50 linear meter (\$25 per linear foot) for G4 (2W) - 6" x 8" wood.
- Item 12. Repair Cost/Accident. For the purpose of this project, \$500 was used as the average cost of repairing hit guardrail.
- Item 13. Maintenance Cost/Year. Based on the data provided by KDOT, the maintenance cost was \$3.00 per linear meter (\$1.00 per linear foot).
- Item 14. Salvage Value. For the purpose of this project, the salvage value was assumed to equal \$0.
- Item 15. Present Worth/Highway Department Costs. ROADSIDE calculates the total present worth (TPW) of accident costs and highway department costs incurred over a specified analysis period (the project life) using the following equation:

$$TPW = CA (KC) \pm CI + ARC + CM (KT) - CS (KJ)$$
 where:
 CA = Accident cost based on initial collision frequency
 KC = Factor to account for project life, discount rate, and traffic growth rate
 CI = Installation cost
 ARC = Present worth of accident report cost = $1 KC(CDi) (Cfi)$
 Cdi = Average collision damage repair costs for sides, corners, and face Cfi.
 Initial collision frequencies for sides, corners, and face
 CM = Annual maintenance cost
 KT = Factor to account for the project life and the discount rate
 CS = Salvage value of feature being studies
 J = Factor to account for the project life and the discount rate
 ROADSIDE also calculates annualized costs, which are obtained by multiplying present worth values by a capital recovery factor (CRF).

RESULTS

Results are from a cost-effectiveness analysis based on several assumptions, that are both input to the ROADSIDE program and inherent within the program; therefore, the results should be used with judgement after considering other, non-economic factors. A sample of Kansas results are presented below. Detailed results were incorporated in approximately 140 graphs and tables and several summary tables (5).

Roadside Obstacle

RCB Culvert - Straight Wings

Based on the total life cycle cost analysis, the guardrail was economically justifiable for speeds of 90 km/h, ADTs of 300 or higher and culvert end height of 2.4 meters. The results indicated that the guardrail was not economically justified if the culvert's lateral offset from the nearest driving lane was two or more meters.

RCB Culvert - Flared Wings

The study results indicated that, under all conditions, guardrail was not economically justified if the culvert's lateral offset from the edge of the nearest driving lane was more than three meters. For some other conditions, installation of guardrail was economically justifiable.

RCP Culvert - Pipe/Headwall

The study results indicated that the guardrail was not economically justified if the average daily traffic was 100. Guardrail was economically justifiable for some other conditions.

Utility Poles

Based on the total life cycle cost analysis, the guardrail was economically justifiable for speeds of 90 km/h, ADTs of 400 and lateral offset of 0.0 m and 0.3 m.

Embankments

The study results concerning guardrail installation on roadside embankments indicated that the guardrail was not economically justified for either 1:4 and 1:3 foreslopes with slope surface condition B, regardless of the design speed and ADT. For 1:3 foreslopes with slope surface condition C, ADT of 400, speed of 90 km/h and height of fill of four or more meters installation of the guardrail was economically justifiable. Guardrail was economically justifiable on most 1:2 foreslopes with surface condition B and C. (Surface conditions A, B and C relate to the condition of the roadside with C being the roughest.)

CONCLUSIONS

Application of the ROADSIDE microcomputer program produced valuable results that should provide for a more cost effective use of guardrail on rural, low-volume roads in Kansas. It is important to

note that the procedures and input parameters used in this study were based on the latest Kansas information available at the time. Other jurisdictions should input parameters that apply to their jurisdiction. Also, considerations beyond cost-effectiveness may be important.

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